AD-A131 460 GEOTHERMAL POTENTIAL OF MARINE CORPS MOUNTAIN WARFARE TRAINING CENTER AT PICKEL MEADOW CALIFORNIA(U) NAVAL WEAPONS CENTER CHINA LAKE CA K DANTI ET AL. MAY 83 1/1

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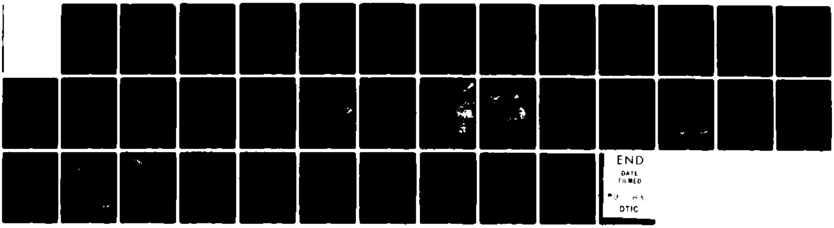

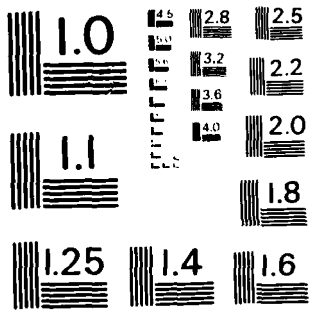

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NWC Technical Memorandum 4898

GEOTHERMAL POTENTIAL
OF
MARINE CORPS
MOUNTAIN WARFARE TRAINING CENTER
AT PICKEL MEADOW, CALIFORNIA

by

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Geothermal Utilization Division
Public Works Department

May 1983

NAVAL WEAPONS CENTER
China Lake, CA

FOREWORD

The work described in this report was performed by the Naval Weapons Center during August 1981, and was authorized and funded by the Naval Civil Engineering Laboratory, Port Hueneme, California, under Project No. Z0829-01-520A.

This report presents interim findings on the geothermal exploration of the Marine Corps Mountain Warfare Training Center, Pickel Meadow, California, and the surrounding area.

The report has been reviewed for technical accuracy by C.F. Austin and J. A. Whelan.

C. F. Austin, Head
Geothermal Utilization Division
Public Works Department
13 May 1983

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A

INTRODUCTION

The Geothermal Utilization Division at the Naval Weapons Center (NWC) was tasked to perform a geothermal exploration program at the Marine Corps Mountain Warfare Training Center (MWTC) at Pickel Meadow (near Bridgeport), California. The program was implemented to determine which of MWTC's lands, if any, contained adequate geothermal resources to develop energy self-sufficiency for the central facilities located at MWTC.

The Marine Corps Mountain Warfare Training Center, Pickel Meadow, Bridgeport, California, was investigated in two sections: (1) the main encampment area at Pickel Meadow (see Figure 1; all figures are located at the end of the report), and (2) the proposed family housing areas in Antelope Valley. Both areas appear to have a high potential for space heating and possibly even electrical power generation, since throughout these areas warm wells, hot springs, and warm springs occur.

The Pickel Meadow area is U.S. Forest Service land. The Marine Corps has a long-term use permit for these lands. At the time of this writing, no military fee-acquired lands existed in this area. Antelope Valley consists mainly of privately owned land, some Forest Service land, and Bureau of Land Management (BLM)-administered lands. The Naval Facilities Engineering Command (NAVFAC) is conducting a study to determine which lands are economically feasible for the proposed family housing units. The area that will be used for the housing will probably be fee-acquired.

MWTC lies on the lower eastern slopes of the Sierra Nevada in northwestern Mono County. The Sweetwater Mountains are to the east. The main encampment of MWTC is on the northern side of Pickel Meadow. Major drainage through the entire area is by the West Walker River. Bridgeport lies about 17 miles (27.4 km) to the southeast and Antelope Valley is about 15 miles (24 km) to the north. U.S. Highway 395 is the major highway through the region running in a north-south direction. State Highway 108 (Sonora Pass) passes east-west. The main encampment is located 4 miles (6.4 km) west along Highway 108 from the intersection of these two highways.

CLIMATE AND VEGETATION

The elevation varies considerably from 5,000 feet (1,525 m) in Antelope Valley to peaks that are over 10,000 feet (3,048 m) above sea level. The climate is largely a function of elevation. At the higher elevations, precipitation is about 40 inches (101.6 cm) per year. Temperatures are characterized by one monthly average between 50°F (10°C) to 64.6°F (18°C) and at least 4 months with average temperatures of less than 33.8°F (1°C) (Slemmons, 1953). The lower altitudes are semi-arid. The Bridgeport area (6,470 feet, 1,972 m) receives 8 inches (20.3 cm) of precipitation annually (Martin et al., 1980). Precipitation at all elevations is mostly by snowfall; however, frequent thundershowers do occur during the summer months.

Vegetation ranges from sagebrush types in the lower elevations to Juniper, Pinon, Jeffrey, and Lodgepole pine and Douglas Fir in the higher elevations.

GEOLOGY OF AREA

BACKGROUND

A generalized geological map of the area is shown as Figure 2.

Halsey (1953) has mapped parts of the Fales Hot Springs and the Desert Creek Peak quadrangles. The Dardanelles Cone and Sonora Pass quadrangles were mapped by Slemmons (1953). Curtis (1951) mapped the Topaz Lake and the eastern half of the Ebbetts Pass quadrangles. Priest (1979) has studied the volcanic rocks of the Sonora Pass and the Fales Hot Springs quadrangles in detail. Priest's (1979) geologic map is shown as Figure 3. He notes that the lavas are highly potassic, latitic lavas and tuffs from 8.6 to 10.0 million years old. He states that "a great deal of evidence supports the formation of volcano-tectonic depression..." Fales Hot Springs, the main encampment of MWTC, and the Leavitt Lake Road Spring are all on the northern edge of the collapse caldera. As will be detailed in a later section on hydrology and geochemical geothermometry, it is highly probable that the water of Leavitt Lake Road Spring contains a geothermal component. Austin et al (1971) note that most of the major geothermal areas of the world are associated with this type of structural pattern.

The proposed housing areas are located in Antelope Valley in Recent alluvium off Highway 395 to the north of MWTC. The Antelope Valley is a graben bounded by north-south faults. The mountains to the west contain Mesozoic granitic rocks and pre-Cretaceous metamorphosed sedimentary rocks, while across the valley are Mesozoic granitic and Cretaceous rocks. Warm wells occur at the town of Walker (Antelope Valley), which probably indicates that hot water is rising along the graben boundary faults. The following discussion of the geology has been abstracted from Halsey (1953).

PRE-TERTIARY GEOLOGY

The lower Jurassic sediments of Leavitt Meadow contain quartz-diorite pebbles and boulders. These particles are considered to be the oldest rocks in the country north of Mono Lake. In the Sweetwater Range and vicinity, remnants of metamorphosed pre-Nevadan (Jura-Trias) rocks occur as discontinuous outcrops separated by Nevadan intrusive rocks or by Tertiary volcanic cover. These metamorphosed rocks, which were part of the early Mesozoic geosyncline, have been extensively folded and/or altered. During the upper Mesozoic, the folded pre-Nevadan rocks were intruded by a series of plutons. The early plutons were small bodies of quartz-gabbro and quartz-diorite. They were followed by the predominant early Nevadan intrusives that were granodiorite or a basic quartz monzonite. More basic and acidic bodies are present but they are uncommon. After these early plutons cooled, they were intruded by large plutons of granodiorite to quartz-monzonite. These rocks are exposed extensively west of the West Walker River.

TERTIARY GEOLOGY

The oldest Tertiary volcanic rocks are exposed as several small flow remnants of welded rhyolite tuff between the West Walker River and Mill Creek and also between Mill Creek and Lost Cannon Creek. These volcanic rocks are of upper Eocene age. Propylitized andesites are exposed along the Mt. Emma ridge. The Mt. Emma andesites cover an area of about 30 square miles and are bounded by Leavitt Meadow, Pickel Meadow, Sonora Junction Valley, and Burt Canyon. In this area, the andesitic series are from 1,000 to 2,500 feet thick. Miocene sediments crop out along the northeastern side of Antelope Valley. These sediments were deposited during the erosional interval between Oligocene volcanism and late Miocene volcanism. The Mio-Pliocene andesitic rocks of the Walker River drainage basin are the most extensive of all the Tertiary volcanic rocks. The Mio-Pliocene andesitic rocks are derived mainly from the Lost Cannon Peak intrusive center. This center covers an area of about 8 square miles north of Pickel Meadow and east of Lost Cannon Peak. The andesites are at least 2,500 feet thick. They consist of autobrecciated flows, sills, intrusions, several dozen lahars, and several horizons of andesitic sediments. These sediments are well exposed on the scarp sides of two large tilted fault blocks north of Pickel Meadow. A latitic series of flows and tuffs overlies the Mio-Pliocene andesites (Mehrten Formation). This series is further divided into the Table Mountain Member, the Welded Tuff Member, the Pumice Tuff-Breccia Member, and the Alkaline Basalt Member. The middle Pliocene latite series extends across the entire width of the Sierra Nevada into the western Great Basin. East of Sonora Pass, the Table Mountain latites reach a maximum thickness of 100 feet, and are exposed to a thickness of approximately 400 feet just east of Lost Cannon Peak. About 250 feet of latites representing at least four flows are exposed along the West Walker River east of Lost Cannon Peak. Welded tuffs are exposed in the Fales Hot Springs area and in the Lost Cannon Peak area. The Pumice Tuff-Breccia Member is represented by only a few scattered outcrops. Present exposures are approximately 50 feet thick. They outcrop along the east wall of the West Walker River Canyon. The Alkaline Basalt Member is exposed as a small remnant between Lost Cannon Creek and Little Antelope

Valley. It also outcrops on the west bank of Mill Creek. Mid-Pliocene intermediate and acid rocks occur as intrusions and short flows. Their composition ranges from hornblende acid andesites to rhyolites. Several of these intrusions are exposed south of Antelope Valley between the Leavitt Meadow-Slinkards Valley fault. Most of the intrusions are exposed in the Mio-Pliocene volcanic terrane north of Leavitt Meadow. Exposures of late Pliocene olivine basalts occur as small domes, intrusions, and flow remnants. The largest number of exposures are in the subsummit area of the Sweetwater Range. The flow remnants range in thickness from about 50 to 150 feet.

QUATERNARY GEOLOGY

Basaltic andesite is exposed within 2 miles of Volcanic Butte. Volcanic Butte is a conical plug or dome lying 3 miles south of Fales Hot Springs. The andesite is about 400 feet thick at Volcanic Butte. A few short flows have thicknesses up to 200 feet. The andesite is between early and mid-Pleistocene in age. It is probably younger than the Sherwin glacial stage.

Pickel Meadow and Sonora Junction Valley lie in Recent alluvium surrounded by Pleistocene glacial deposits. Leavitt Meadow lies in Recent alluvium.

STRUCTURE

A generalized quaternary structural map of the area between Antelope Valley and south of Mt. Emma is shown as Figure 4.

The present western border of the Great Basin proper is the Leavitt Meadow-Slinkards Valley fault. The complex fault-block structure of the Basin and Range is present east of this fault. The structural and physiographic trends of the Sierra Nevada are predominant west of the fault.

Pleistocene faulting, east of the Sierra Nevada crest, is the major process responsible for the present physiographic character. These structural units have been only slightly modified by canyon cutting, Pleistocene glaciation, and valley sedimentation.

A narrow zone of untilted blocks is located between the Leavitt Meadow-Slinkards Valley fault block zone (1 to 3 miles wide) and the Sweetwater Range. The zone extends from the south end of Antelope Valley to just south of Mt. Emma. From Antelope Valley, the blocks rise steplike in elevation from 6,500 feet to 11,000 feet on Hanging Valley Ridge south of Mt. Emma.

Sonora Junction Valley is a graben of many blocks partly concealed by glacial moraines and outwash sediments. The West Walker River scarp (2,500 to 3,000 feet) bounds it on the west. The eastern edge is defined by blocks that rise only a few hundred feet.

Antelope Valley is a graben bounded on the west by the West Walker River-Antelope Valley fault (500 to 2,000 feet high) and on the east by the Wellington Hills fault.

Leavitt Meadow and Pickel Meadow are typical "U-shaped" valleys. These valleys were filled by the glaciers of the Tioga, Tahoe, and Sherwin stages. The Sherwin stage glacier was the largest system east of the Sierra Nevada crest. This glacier covered an area of about 200 square miles and reached thicknesses up to 2,500 feet.

Fales Hot Springs and Huntoon Valley are areas that have large accumulations of outwash gravels. Old till remnants of probable McGee age are found north of Fales Hot Springs, above Volcanic Butte, and between Mill Creek and the West Walker River.

WATER GEOCHEMISTRY

Eleven water samples were collected and analyzed (Table 1). Nine of these were in the Fales Hot Springs-Pickel Meadow area; two were in the Coleville (Antelope Valley) area. In the Fales Hot Springs-Pickel Meadow area one of the waters collected was a surface water; the remaining samples were taken from springs.

TABLE 1. Water Sample Identification.

Sample no.	Name/general location	Water source	Location (section, township, range)
1	Summit Meadows	Spring	Sec 36, T7N, R22E, MDM[a]
2	Sonora Bridge	River	Sec 17, T6N, R23E
3	Fales Hot Springs	Spring	Sec 24, T6N, R23E
4	Unnamed	Spring	NE 1/4, Sec 20, T6N, R23E
5	Unnamed	Spring	Sec 1, T6N, R23E
6	Northwest of Sardine Meadow	Spring	Sec 36, T6N, R21E
7	Near Devil's Gate	Spring	SW 1/4, Sec 19, T6N, R24E
8	Unnamed	Spring	Sec 11, T6N, R22E
9	Leavitt Lake Road	Spring	Sec 7, T5N, R22E
10	West Walker River at Cunningham Road Bridge	River	Sec 36, T9N, R22E
11	Coleville General Store	Well	Sec 1, T8N, R22E

[a]Mount Diablo meridian.

Analyses are given in Table 2. Piper diagrams of these waters are shown as Figure 5. Sampling points are shown as Figures 6 and 7. Sample Nos. 2, 4, 5, 6, and 8 group tightly on the Piper diagrams as calcium-magnesium-bicarbonate waters. The similarity of the spring waters to the West Walker River water indicates these waters represent the shallowest surface aquifers, where short transit times have caused little change due to water-rock-soil interaction. This is also indicated by the general good quality of the water and low total dissolved solids (110 ppm for the West Walker River, 116 to 201 ppm for the springs).

Fales Hot Springs (No. 3), the cold spring (No. 7) adjacent to Fales Hot Springs, and Leavitt Lake Road Spring (No. 9) form an interesting trio. These are high sodium-potassium-bicarbonate waters. The authors group these together. To look at the relationship between these waters more closely, we considered the chloride-to-sulfate ionic ratios. The ratios are Fales: cold spring: Leavitt = 1.42:NA*:1.47. The relatively high sulfate content could indicate steam transport. A real possibility is that vapors are heating and modifying the cold waters creating Fales Hot Springs. The Leavitt Lake Road Spring is higher in calcium and bicarbonate than the Fales Hot Springs water. This represents shallow Pickel Meadow waters also modified by vapors somewhere in the hydrologic system. It should be noted that while sample No. 7 has low dissolved solids (230 ppm), Fales Hot Springs and Leavitt Lake Road Spring have very similar dissolved solids (2,288 and 2,399 ppm, respectively).

The third group of waters includes the West Walker River near Coleville (No. 10), the store at Coleville (No. 11), and the Summit Meadow Spring (No. 1). The Summit Meadow Spring has only about one-third (69 ppm) the dissolved solids of the West Walker River (216 ppm) or the Coleville store (233 ppm).

CHEMICAL GEOTHERMOMETRY

The various geothermometers are given in Table 3. The results group according to the geochemical interpretations of the previous section.

Since Fales Hot Springs, sample No. 7, and Leavitt Lake Road Spring seem to be related to a geothermal reservoir, mixing models were made mainly using these samples.

The chloride mixing model of Fournier (1979) was made using quartz steam-flashing temperatures to obtain enthalpies (Figure 8). This is concordant with the geochemical model of the previous section. Using the Devil's Gate sample (No. 7), Leavitt Lake Road Spring (No. 9), and Fales Hot Springs (No. 3), a reservoir temperature of 180°C is obtained. If the spring northwest of Sardine Meadow (No. 6) is used, a reservoir temperature of 220°C is obtained.

*Not analyzed.

TABLE 2. Water Analyses of Spring, Well, and River Waters.[a]

Constituent	Constituents in ppm for Sample No. Noted in Figure 5										
	1	2	3	4	5	6	7	8	9	10	11
Calcium	4.5	17.0	33.5	22.5	9.0	14.5	1.0	13.5	66.0	18.0	22.5
Magnesium	2.0	3.0	10.0	6.5	5.0	4.5	0.09	7.5	13.5	5.5	6.5
Sodium	3.6	5.0	570.0	10.5	4.5	4.1	45.0	5.0	530.0	26.0	22.0
Potassium	1.7	0.8	43.0	2.4	3.3	0.9	3.3	5.0	35.0	2.5	2.2
Hydroxide		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Carbonate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate	32.1	67.6	1039.4	128.2	63.2	72.8	121.3	91.0	1450.9	100.5	117.8
Chloride	<1.8	<1.8	156.8	<1.8	<1.8	<1.8	<1.8	<1.8	65.5	24.4	<1.8
Sulfate	<5.0	7.0	300.0	<5.0	<5.0	<5.0	<5.0	<5.0	122.0	10.0	32.0
Nitrate	2.7	4.0	0.9	0.9	0.9	0.9	2.7	2.7	0.9	2.7	1.8
Fluoride	0.05	0.08	4.0	0.12	0.07	0.07	0.02	0.05	2.00	0.68	0.32
Iron	...	<0.05	0.05	<0.05	0.99	0.07	0.20	<0.05	<0.05	<0.05	<0.05
Manganese	...	<0.01	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.14	<0.01	<0.01
Arsenic	...	<0.01	0.35	0.01	<0.01	<0.01	0.02	<0.01	0.10	<0.01	0.01
Copper	...	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.08
Zinc	...	0.01	0.04	0.01	<0.01	0.03	0.01	<0.01	0.01	0.03	0.13
Total dissolved solids	69.0	110.0	2288.0	201.0	126.0	116.0	230.0	157.0	2399.0	216.0	211.0
Mercury	...	<0.0002	<0.0002	0.0002	<0.0002	<0.0002	<0.0002	<0.0002	0.0005	0.0002	<0.000[illegible]
Silica	22.0	6.0	121.0	25.0	39.0	18.0	57.0	32.0	113.0	24.0	28.0
Aluminum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Boron	0.08	0.06	5.4	0.01	0.04	0.01	0.06	0.12	0.92	0.66	0.12
Phosphate	<0.1	<0.1	0.9	0.2	0.2	<0.1	0.7	<0.1	<0.1	<0.1	<0.1
Bromide	...	<0.1	0.5	5.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ammonium	0.2	0.4	0.7	0.4	<0.2	<0.1	<0.2	<0.2	<0.2	0.8	[illegible]
Lithium	<0.1	<0.01	1.40	<0.01	<0.01	<0.1	0.01	<0.01	0.38	0.03	[illegible]

TABLE 2. (Contd.)

Constituent	Constituents in ppm for Sample No. Noted in Figure 5										
	1	2	3	4	5	6	7	8	9	10	11
Electrical conductivity, micromhos	59.0	131.0	2700.0	210.0	110.0	126.0	185.0	153.0	2550.0	270.0	250.0
Laboratory pH	8.1	7.7	7.3	7.5	6.8	7.4	7.4	7.6	6.8	7.9	7.2
Field pH	<5.6	5.6	6.8	5.8	5.9	5.6	5.6	5.6	6.8	5.5	6.0
Flow, gpm	5.	...	2000.	100.	5.	10.	3.	10.	10.	...	...
Temp., °C	17.	11.	59.5	15.	10.	11.	13.5	13.	19.	19.	20.
Date sampled	8/25/81	8/25/81	8/24/81	8/24/81	8/24/81	8/24/81	8/24/81	8/25/81	8/24/81	8/26/81	8/26/81

[a]Laboratory analyses by B. C. Laboratories, Bakersfield, Calif.

TABLE 3. Chemical Geothermometers.

Geothermometer	Calculated temperature in °C for water sample noted										
	1	2	3	4	5	6	7	8	9	10	11
Quartz, conductive cooling[a]	76	30	162	81	101	68	120	92	158	80	86
Chalcedony, conductive cooling[a]	35	...	123	40	60	27	79	51	118	39	45
Quartz, steam flashing[a]	72	33	142	77	93	65	108	85	139	75	81
Na-Li[b]	141	118	132	74	125	131	12	118	60	84	94
Na-K (modified)[c]	400	261	194	300	479	295	192	548	184	214	217
Na-K-Ca (B = 4/3)[a]	41	6	174	32	49	9	124	54	141	45	36
Na-K-Ca (B = 1/3)[a]	...	...	182	...	...	...	167	...	168	...	...
Na-K-Ca-Mg[d]	e	e	78	e	e	e	156	e	83	e	e

[a] R. O. Fournier (1977).
[b] C. Fouillac and G. Michard (1981).
[c] R. O. Fournier (1979).
[d] R. O. Fournier and R. W. Potter (1979).
[e] Does not apply.

Using the silica-mixing model of Truesdell and Fournier (1977) (Figure 9), with steam flashing at 100°C, one obtains a reservoir temperature of 162°C by using the Devil's Gate sample (No. 7) and Fales Hot Springs (No. 3). A temperature of 290°C is obtained when the spring northwest of Sardine Meadow (No. 6) and Leavitt Lake Road Spring (No. 9) are used.

Thus, chemical geothermometry indicates a good possibility of a resource more than adequate for space heating, and possibly adequate for power generation.

SOIL GEOCHEMISTRY

A regional soil survey was conducted during the initial field reconnaissance. The soil samples were collected and analyzed by NWC's Geothermal Utilization Division. Samples were taken every 0.5 mile along existing accessible roads. The samples were later analyzed for mercury content in parts per billion. The results were inconclusive due to many problems, which included a very wide range of soil types and inadequate grid coverage of the area. The area was not covered as originally planned due to the fact that much of the forestry lands are classified as "wilderness areas," in which case vehicle access is not permitted. Available field time did not allow for the walking of all the traverses.

THERMAL GRADIENT DRILLING

To understand the hydrology and to get a general view on the geothermal potential, thermal gradient drilling is considered highly desirable. A minimum program should include one hole at the main encampment and one hole at each of the proposed housing sites. Since shallow anomalies may be offset from the resource at depths, such drilling would not necessarily prove the existence of or define a resource, but the data could be used for comparison with the gradients of the Sierra Nevada (0.33 to 1.38°F/100 feet; 0.6 to 2.5°C/100 m) (Sass et al., 1971). This comparison could give a good indication if any potential exists.

Of special note is the fact that Getty Oil, in a joint venture with Mono Power, has drilled 16 thermal gradient and one observation (or stratigraphic) hole in the area (Table 4, Figures 10 and 11). Of particular interest are: hole C20-39, a gradient hole less than 3 miles from the eastern boundary of MWTC; hole SC14-5, an observation hole (a deep hole could furnish significant data on stratigraphy/lithology and hydrology); and gradient holes C19-54, C32-46, C4-45, and C7-47 which surround the proposed housing areas.

TABLE 4. Getty Oil Thermal Gradient Holes, State Highway 108, U.S. Highway 395, and Antelope Valley.

Location (section township, range)	Hole no.	Depth
Sec 12, T9N, R22E MDM[a]	C13-53	Shallow
Sec 19, T9N, R23E MDM	C19-54	Shallow
Sec 21	C21-52	Shallow
Sec 32	C32-46	Shallow
Sec 4, T8N, R23E MDM	C4-45	Shallow
Sec 7	C7-47	Shallow
Sec 9	C9-47	Shallow
Sec 20	C20-44	Shallow
Sec 21	C21-50	Shallow
Sec 22, T7N, R23 MDM	C22-42	Shallow
Sec 1, T6N, R23E MDM	C1-41	Shallow
Sec 10	C10-40	Shallow
Sec 14	SC14-5	Intermediate
Sec 20	C20-39	Shallow
Sec 24	C24-35	Shallow
Sec 27	C27-36	Shallow
Sec 25, T6N, R24E MDM	C25-37	Shallow

[a]Mount Diablo meridian.

THERMAL DATA

Table 5 lists known thermal wells and thermal springs in the project area, three of which, MO-1, MO-2, and MO-3, are located in Antelope Valley. Definite temperatures are not available because they are reported only as being "warm." However, these waters are probably greater than 80°F (26.7°C) (Higgins, 1980). Data from MO-4 and MO-5 are from Fales Hot Springs and the Magma Power Co. well, respectively. MO-5 has a geothermal gradient of 14°F/100 feet (26°C/100 m), which is well above the average thermal gradients for the Sierra Nevada (0.33 to 1.38°F/100 feet, 0.6 to 2.5°C/100 m) or the Basin Ranges (1.65 to 2.75°F/100 feet, 3 to 5°C/100 m).

An additional note is that when the water samples described in the previous sections were collected, the measured temperatures were all greater than the mean air temperature of Bridgeport (41.4°F, 5.2°C) (Hannah, 1975).

TABLE 5. Thermal Wells and Thermal Springs, Pickel Meadow and Antelope Valley.[a]

No.	Type	Latitude DD.MMSS[b]	Longitude, DD.MMSS	Temperature, °C	Other
MO-1	Spring	38.3736	119.3015	Warm	370 T.D.S.[c]
MO-2	Well	38.3130	119.2830	Warm	...
MO-3	Well	38.3200	119.2800	Warm	...
MO-4	Spring	38.2102	119.2401	82	2400 T.D.S.
MO-5	Well	38.2100	119.2400	38	126 m deep

[a] From Higgins (1980).

[b] Degrees, minutes, seconds.

[c] Total dissolved solids.

GRAVITY AND AEROMAGNETICS

Previous gravity surveys were conducted on a regional scale (Oliver et al., 1973). Compilation of these data and unpublished data was completed by Oliver et al., 1980. Aeromagnetic surveys were flown at various scales by the U.S. Geological Survey (USGS) (1971), and Zeitz et al., 1969. Even though the gravity and aeromagnetics data were of a regional nature, a few trends can be noted as follows.

The area containing Fales Hot Springs, Pickel Meadow, and Antelope Valley lies within or on the sides of a large northward elongated regional gravity low (Oliver et al., 1980), which corresponds somewhat to a large regional magnetic low (Zeitz et al., 1969). The gravity low extends south toward Bishop and includes the collapse calderas of Mono Lake, Long Valley, and Round Valley, in addition to the Mono Craters. Does this represent a rifting structure as seen in the Imperial Valley, with a rising of the mantle toward the surface? The magnetic signature is similar to the gravity and shows the largest regional lows over the Mono Craters and the Mono Lake caldera. The map (Zeitz et al., 1969) does not extend far enough south to delineate the magnetic signature over the Long Valley caldera.

In the project area, the aeromagnetics possibly delineate the Little Walker Volcanic Center (collapse caldera) of Priest (1979) near MWTC. This is not seen clearly by gravity data because of post-collapse faulting that might obscure this feature. However, to the north of the caldera the gravity becomes lower, while there is a slight rise and then a drop in the magnetics. This would seem to indicate possible deep-seated heat in the area of Antelope Valley. More detailed gravity and magnetic surveys are needed to delineate the structure.

CONCLUSIONS AND RECOMMENDATIONS

The geology, water geochemistry, and chemical geothermometry indicate a high probability of a geothermal resource at MWTC, with high enough temperatures for space heating and a good probability of a resource with adequate temperatures for power production.

On the central-eastern frontal area of the Sierra Nevada, many volcanic centers and collapse calderas are known to exist. Thermal wells and springs occur throughout the project area. The previous geophysical surveys show that there might be an association between these features.

Recommended future work is as follows:

1. Obtain thermal data, if possible, from private industry.

2. Conduct gravity, land magnetic, and aeromagnetic surveys of the project areas to delineate subsurface structural features of interest as drilling targets for the production of water suitable for space heating.

3. Perform a deep electrical-resistivity survey to define conductive zones in the Fales Hot Springs area to determine if these zones persist beneath MWTC to the side and extend north to the proposed Antelope Valley housing annex.

4. Drill thermal gradient holes at the main encampment of MWTC.

5. Drill exploratory wells at both MWTC and at the selected family housing site in the Antelope Valley.

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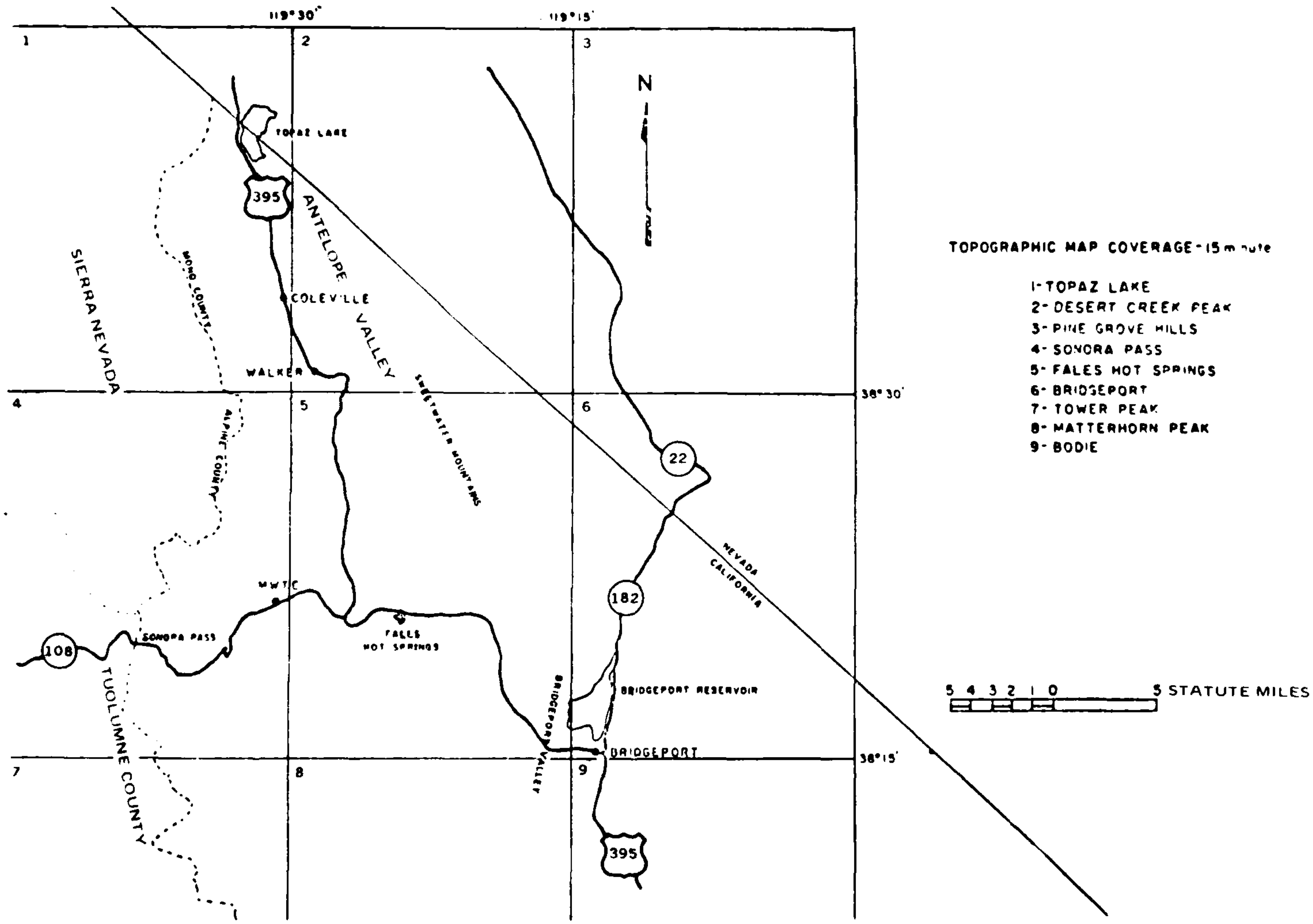


FIGURE 1. Location Map of Mountain Warfare Training Center (MWTC), Pickel Meadow, California.

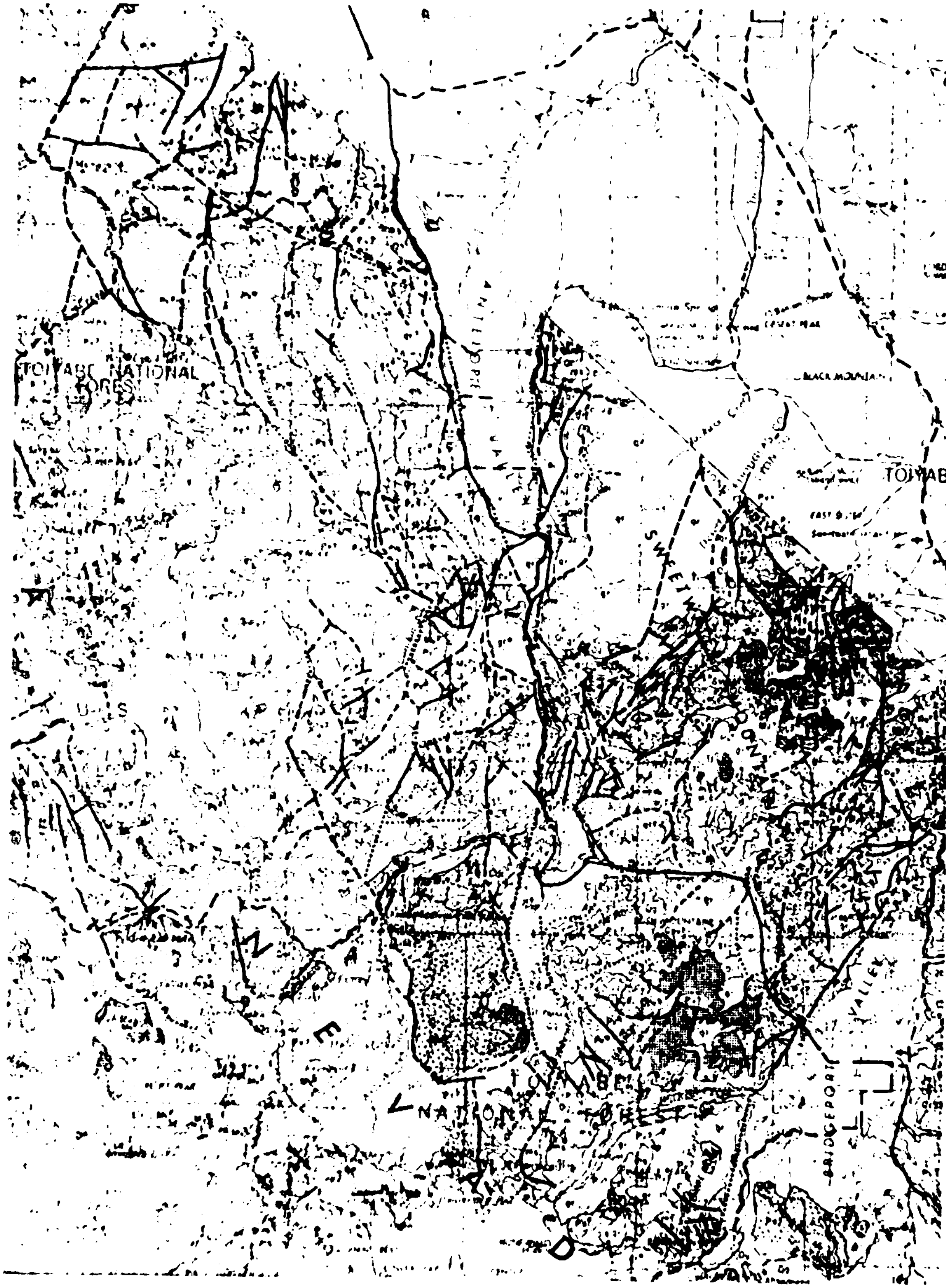
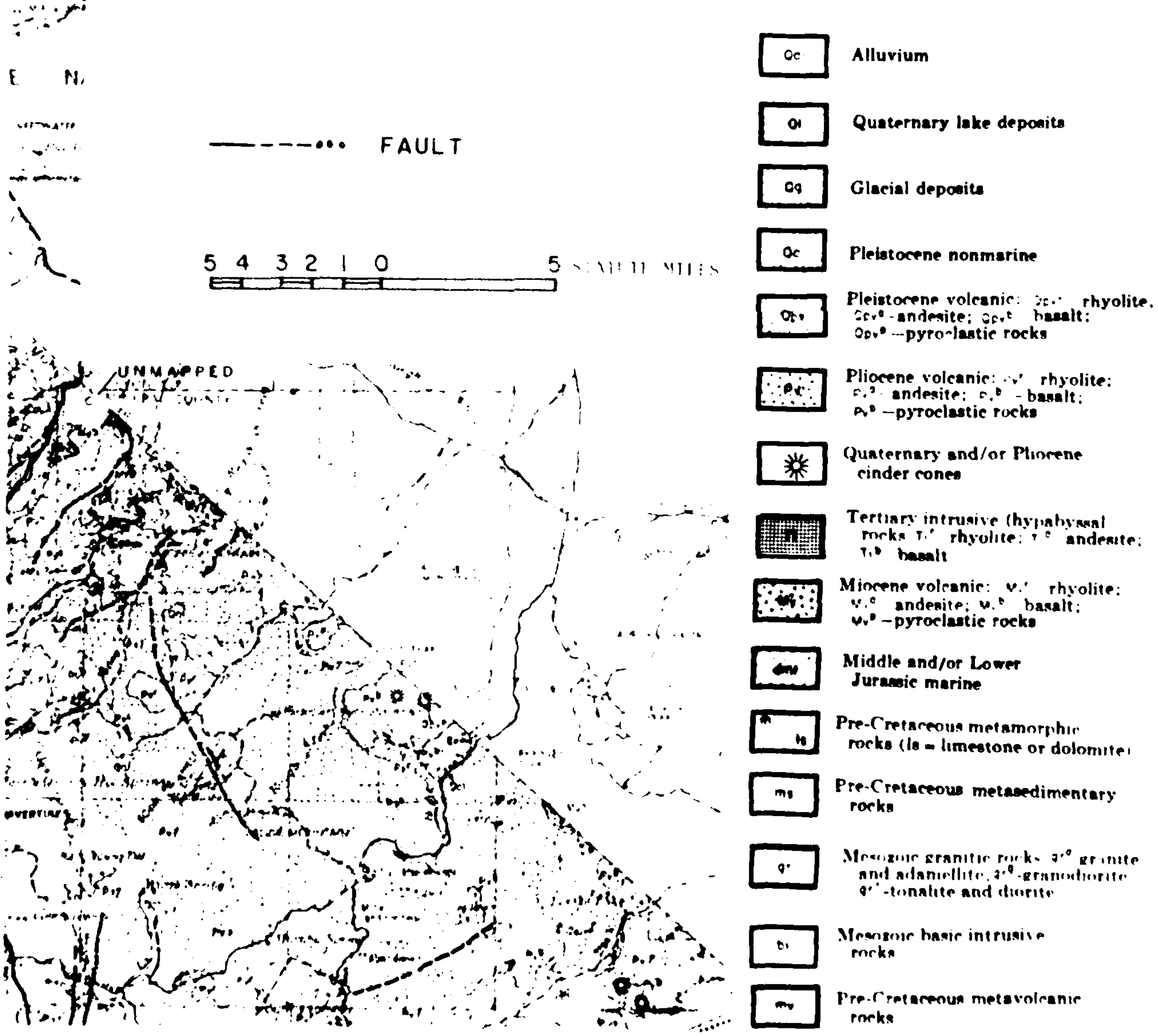

TOIYABE NATIONAL
FOREST
TOIYAB
BLACK MOUNTAIN
BRIDGEPORT VALLEY
NATIONAL

FIGURE 2. Geological Map of Pickel Meadow, Coleville, Bridgeport and the Surrounding Areas, California (Adapted From Koenig (1963)).




O N A L
E S T
Spring
Marine Corps
Cold Weather
Camp
6760
Pickel
Pickel Meadow
RIVER
Kirman
Lake
Silver Falls
Secret
Lake
Roosevelt
Lake
Lane
Lake
RECENT
PLEISTOCENE
LATE
MIOCENE
8.5 - 8.9
MILLION
YEARS
LATE
MIOCENE
9.5 - 10.0
MILLION
YEARS

FLUVIAL, COLLUVIAL, AND LANDSLIDE DEPOSITS

HOT SPRINGS DEPOSITS

GLACIAL DEPOSITS

LAVAS OF MAHOGANY RIDGE

LATITE OF DEVIL'S GATE

UPPER MEMBER OF EUREKA VALLEY TUFF

LAVAS AND TUFFS OF POORE LAKE

FALES HOT SPRINGS QUARTZ LATITE

EUREKA VALLEY TUFF

TABLE MOUNTAIN LATITES

RELIEF PEAK FORMATION PYROXENE HORNBLENDE AND HORNBLENDE ANDESITE FLOWS, MUDFLOWS, AND AUTOBRECCIA } MIDDLE MIOCENE

UNNAMED BASALT AND BASALTIC ANDESITE FLOWS } MIDDLE MIOCENE

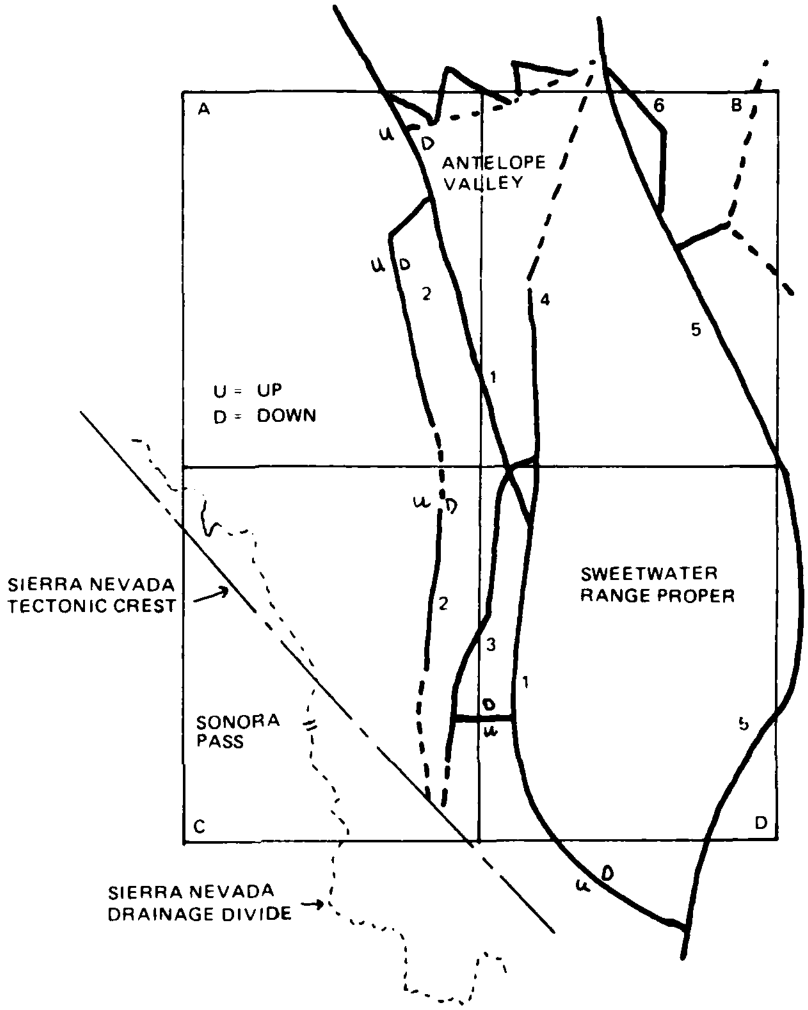
VALLEY SPRINGS FORMATION SANIDINE RHYOLITE ASH FLOWS, SLIGHTLY TO DENSELY WELDED } OLIGOCENE OR EARLY MIOCENE

NEVADAN INTRUSIVE ROCKS } JURASSIC

NORMAL FAULT

MAXIMUM LIMITS OF PROBABLE VOLCANOTECTONIC DEPRESSION

FIGURE 3. Geologic Map of the Little Walker Volcanic Center (adapted from Priest, 1979).



LEGEND

1 - WEST WALKER RIVER--ANTELOPE VALLEY FAULT
2 - LEAVITT MEADOW–SLINKARDS VALLEY FAULT
3 - PICKEL MEADOW–MILL CREEK FAULT
4 - WELLINGTON HILLS FAULT
5 - BRIDGEPORT–WELLINGTON FAULT
6 - BOULDER HILL MINE FAULT

A - TOPAZ LAKE 15-MINUTE QUADRANGLE
B - DESERT CREEK PEAK 15-MINUTE QUADRANGLE
C - SONORA PASS 15-MINUTE QUADRANGLE
D - FALES HOT SPRINGS 15-MINUTE QUADRANGLE

FIGURE 4. Quaternary Structure Map (adapted from Halsey, 1953).

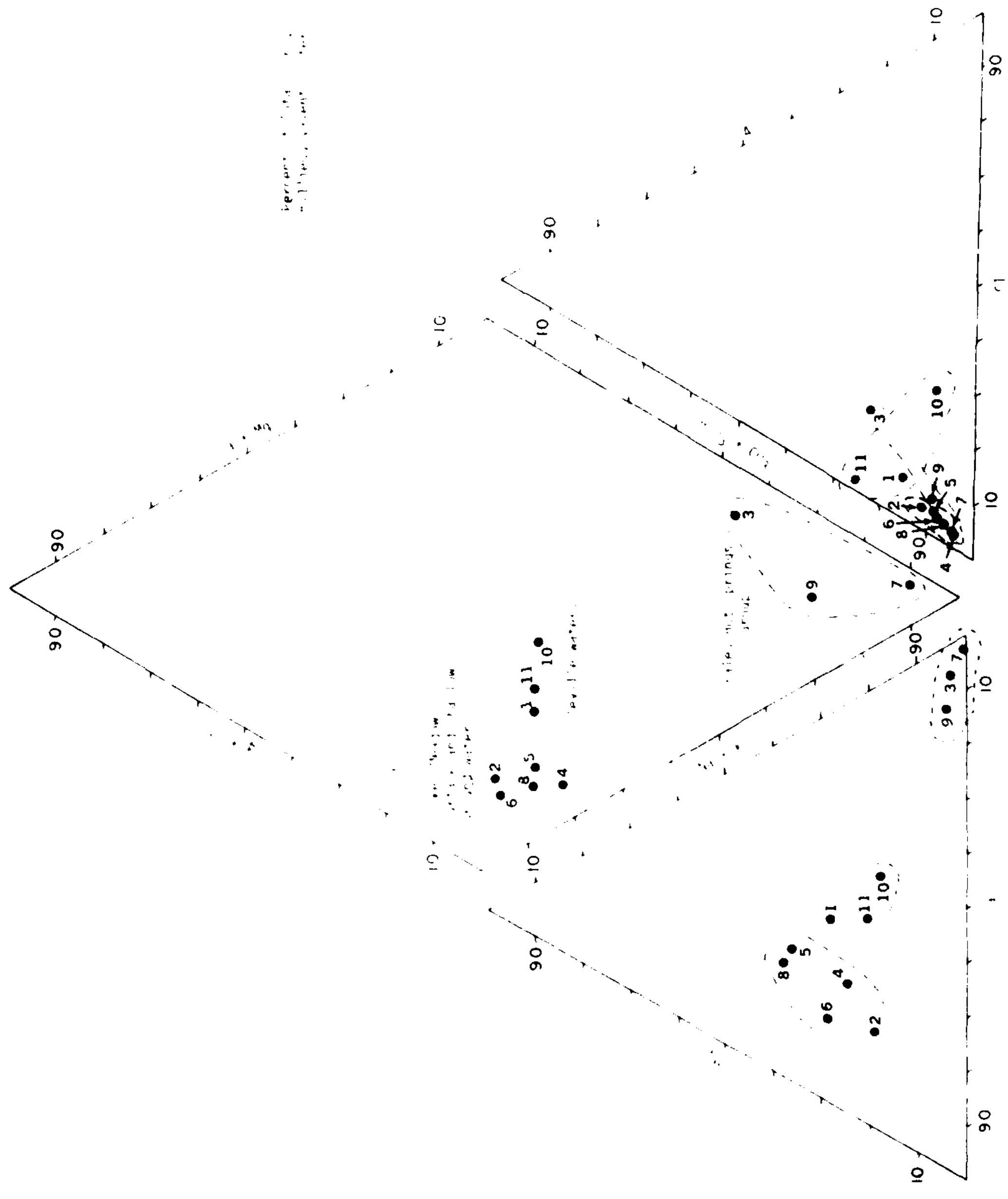


FIGURE 5. Piper Diagrams.

▲ Water Sample Points

⬢ Location of Warm Wells or Warm Springs

FIGURE 6. Water Sample Locations- Coleville Area.

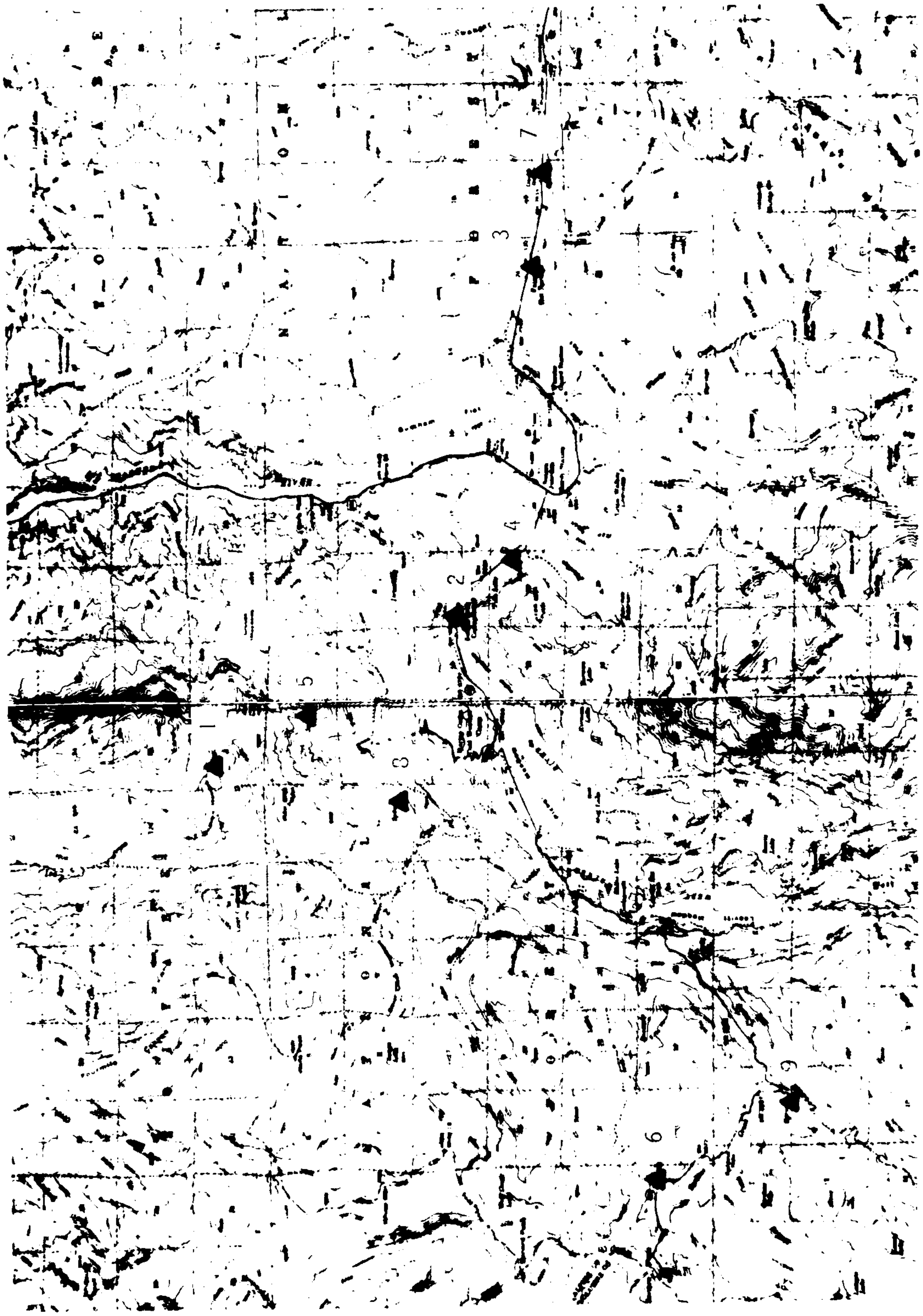


FIGURE 7. Water Sample Locations- Pickel Meadow Area.

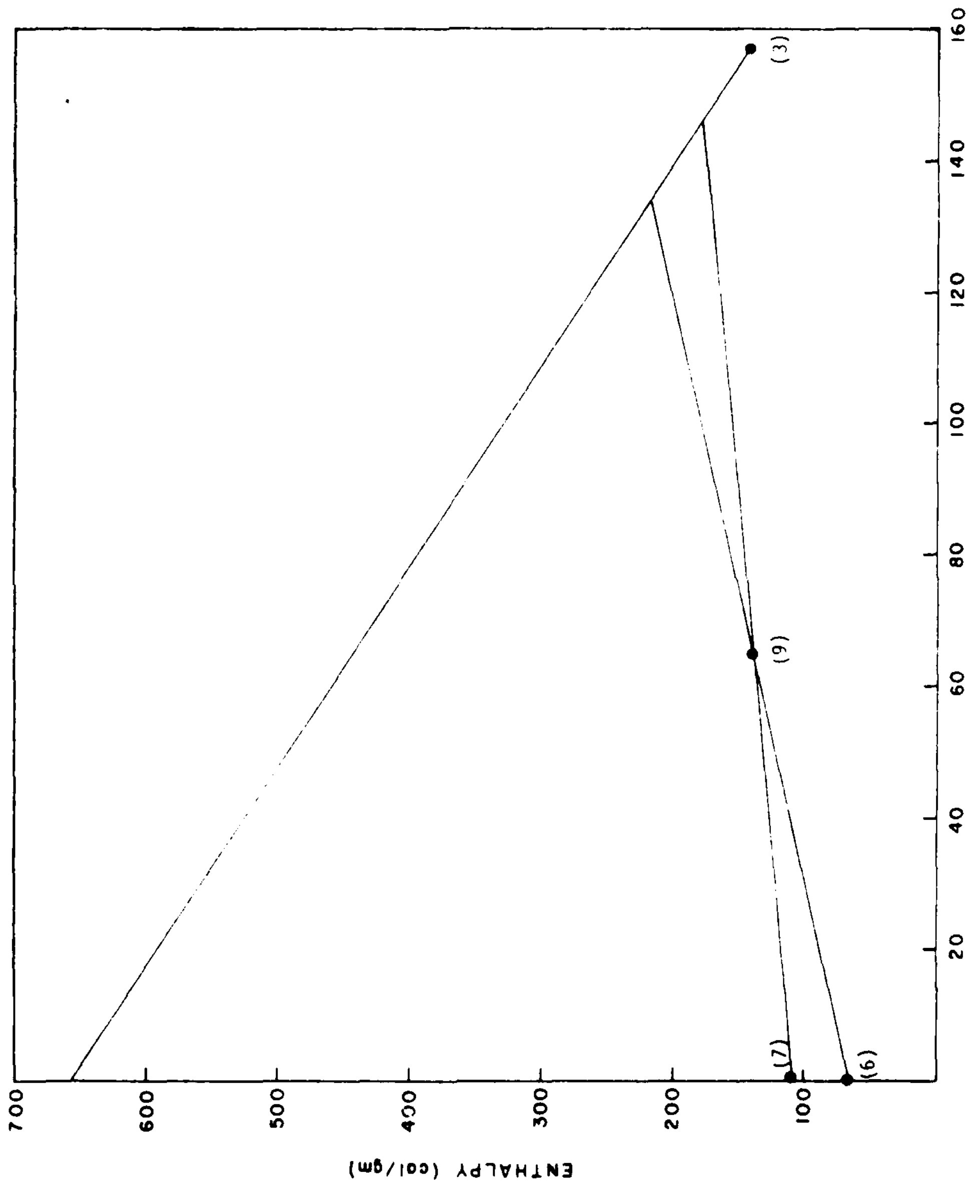


FIGURE 8. Enthalpy-Chloride Diagram, Pickel Meadow.
(See Table 1 for water sample locations.)

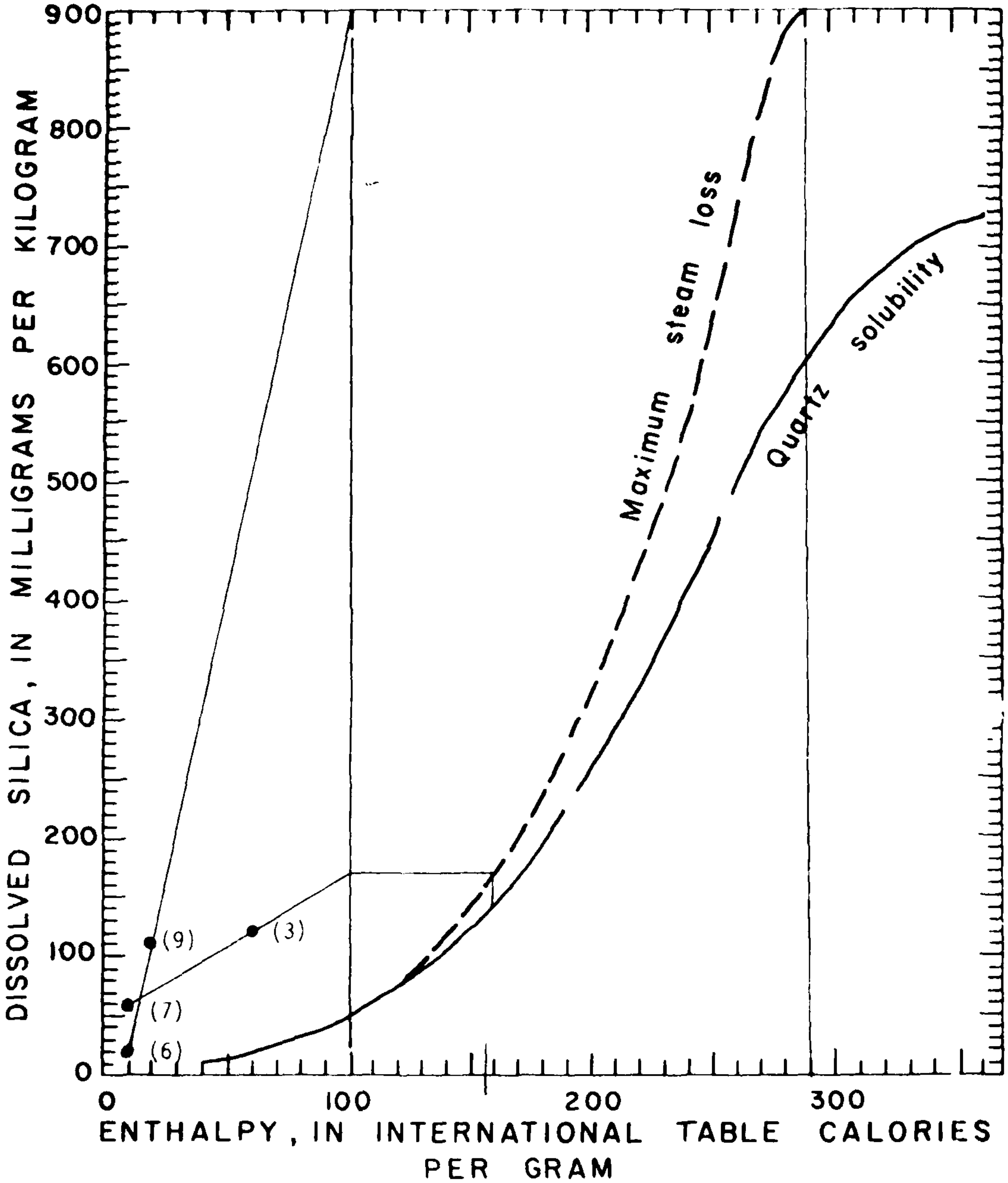


FIGURE 9. Silica-Mixing Model. (See Table 1 for water sample locations.)

FIGURE 10. Getty Oil Thermal Gradient Holes, Antelope Valley.

FIGURE 11. Getty Oil Thermal Gradient Holes, Fales Hot Springs.

BIBLIOGRAPHY

Austin, C. F., W. H. Austin, and G. W. Leonard. "Geothermal Science and Technology, A National Program," Naval Weapons Center Technical Series 45-029-72. (September 1971)

Baker, C. L. "The Nature of the Later Deformations in Certain Ranges of the Great Basin." *Journal of Geology*, Vol. 21 (1913), pp. 273-278.

Ball, S. H. "A Geologic Reconnaissance in Southwestern Nevada and Eastern California." U.S. Geological Survey Bulletin 308. (1907)

Blackwelder, Elliot. "Pleistocene Glaciation in the Sierra Nevada and Basin Ranges." *Geological Society of America Bulletin*, Vol. 42 (1913), pp. 865-922.

Blake, M. C., Isidore Zietz, and David L. Daniels. "Aeromagnetic and Generalized Geologic Map of Parts of Central California." U.S. Geological Survey, Geophysical Investigations Map GP-918. (1978)

California Blue Book (1950), Mono County, pp. 911-912.

California Geological Survey. (Description of Country Between Mono Lake and Sonora Pass.) Vol. 1 (1860-1864), pp. 437-439.

California State Mining Bureau (California Department of Natural Resources, Division of Mines), References to Mineral Resources of Mono County in Annual Reports of the State Mineralogist 8, 12, 13, 15, 17, 18, and 23, and Bulletins 13, 18, 24, 26, 36, 38, 125, and 152.

Chesterman, C. W. "Geology of the Matterhorn Peak Quadrangle, Mono and Tuolumne Counties, California." California Division of Mines and Geology Map, Sheet 22. (1975)

Clark, M. M. "Pleistocene Glaciation of the Drainage of the West Walker River, Sierra Nevada, California." Ph.D. Thesis, Stanford University (1967)

Curtis, G. H. "Geology of the Topaz Lake and the Eastern Half of Ebbetts Pass Quadrangles." Unpublished Ph.D. Thesis, University of California, Berkeley. (1951)

Davis, W. M. "Mountain Ranges of the Great Basin." *Harvard Coll. Mus. Comp Zoology Bulletin*, Vol. 42 (1903), pp. 129-177.

Davis, W. M. "Faults, Underdrag and Landslides of the Great Basin Ranges." *Geological Society of America Bulletin*, Vol. 33 (1922), pp. 92-96.

Fouillac, C. and G. Michard. "Sodium Lithium Ratio in Water Applied to Geothermometry of Geothermal Reservoirs." [illegible], Vol. 10 (1981), No. 1, pp. 55-70.

Fournier, R. O. "Chemical Geothermometers and Mixing Models for Geothermal Systems." [illegible], Vol. 5 (1977), pp. 41-50.

Fournier, R. O. "A Revised Equation for the Na/K Geothermometer." [illegible], [illegible], Vol. 3 (1979), Sept. 1979, pp. 221-224.

Fournier, R. O. "Geochemical and Hydrologic Considerations and the Use of Enthalpy Chloride Diagrams in the Predictions of Underground Conditions in Hot-Spring Systems." [illegible], Vol. 5 (1979), pp. 1-16.

Fournier, R. O. and R. W. Potter. "Magnesium Correction to the Na-K-Ca Chemical Geothermometer." [illegible], Vol. 43 (1979), pp. 1543-1550.

Halsey, J. H. "Geology of Parts of the Bridgeport, California and Wellington, Nevada Quadrangles." Unpublished Ph.D. Thesis, University of California, Berkeley. (1953)

Hannah, J. L. "The Potential of Low Temperature Geothermal Resources in Northern California." California Division of Oil and Gas, Report No. TR13. (1975)

Hem, J. D. "Study and Interpretation of the Chemical Characteristics of Natural Water." U.S. [illegible]ological Survey Water-Supply Paper 1473. (1970)

Higgins, C. T. "Geothermal Resources of California." California Division of Mines and Geology, Geologic Data Map No. 4. (1980)

John, D. A., J. Giusso, W. J. Moore, and R. A. Armn. "Reconnaissance Geologic Map of the Topaz Lake 15-Minute Quadrangle, California and Nevada." U.S. Geological Survey Open-File Report 81-273. (1981)

Koenig, J. B. "Geologic Map of California, Walker Lake Sheet." California Division of Mines and Geology. (1963)

Lachenbruch, A. H. "Preliminary Geothermal Model of the Sierra Nevada." [illegible], Vol. 73 (1968), No. 22, pp. 6977-6989.

Mariner, R. H., T. S. Presser, and W. C. Evans. "Hot Springs of the Central Sierra Nevada, California." U.S. Geological Survey Open-File Report 77-559. (1977)

Martin, R. C., C. T. Higgins, and D. Olmstead. "Resource Assessment of Low and Moderate-Temperature Geothermal Waters in California." Report of the First Year, 1978-1979 of the U.S. Department of Energy-California State-Coupled Program for Reservoir Assessment and Confirmation. (1980)

Muffler, L. J. P. "Assessment of Geothermal Resources of the United States." U.S. Geological Survey Circular 790. (1979)

Noble, D. C., W. R. Dickinson, and M. M. Clark. "Collapse Caldera in the Little Walker Area, Mono County, California." *Geological Society of America*, Special Paper 121, pp. 536-537. (1979)

Noble, D. C., D. B. Slemmons, M. K. Korringa, W. R. Dickinson, Y. Al-Rawi, and E. H. McKee. "Eureka Valley Tuff, East-Central California and Adjacent Nevada." *Geology*, Vol. 2 (1974), pp. 139-142.

Oliver, H. W. "Interpretation of the Gravity Map of California and its Continental Margin." California Division of Mines and Geology Bulletin 205. (1980)

Oliver, H. W., R. H. Chapman, S. Biehler, S. L. Robbins, W. F. Hana, A. Groscom, L. A. Beyer, and E. A. Silver. "Gravity Map of California and its Continental Margin." California Division of Mines and Geology, Geologic Data Map No. 3. (1980)

Oliver, H. W., S. L. Robbins, and W. L. Rambo. "Complete Bouguer Gravity Map of Part of the Walker Lake - 1¼ x 2¼ Quadrangle, California and Nevada." U. S. Geological Survey Open-File Report. (1973)

Paces, T. "Chemical Characteristics and Equilibrium in Natural Water-Felsic Rock-CO_2 System." *Geochemica et Cosmochimica Acta*, Vol. 36 (1972), pp. 217-240.

Priest, G. R., H. R. Bowman, A. J. Herbert, M. L. Silberman, K. Street, and D. C. Noble (1974). "Eruptive History and Geochemistry of the Little Walker Volcanic Center, East Central California." A Progress Report: *Geological Society of America, Abstracts with Programs*, Vol. 6 (1974), p. 237.

Priest, G. R., D. C. Noble, H. R. Bowman, A. J. Herbert, and H. A. Wollenberg. "Eruptive and Geochemical Evolution of the Little Walker Volcanic Center." *California Geology*, Vol. 28 (1975), No. 5, p. 106.

Priest, G. R. "Geology and Geochemistry of the Little Walker Volcanic Center, Mono County, California." Ph.D. Thesis, Oregon State University. (1979)

Priest, G. R., H. R. Bowman, A. J. Herbert, M. L. Silberman, K. Street, and D. C. Noble. "Eruptive History and Geochemistry of the Little

Walker Volcanic Center, East Central California." A Progress Report: *Geological Society of America, Abstracts with Programs*, Vol. 6 (1974), p. 237.

Robbins, S. L. and H. W. Oliver. "Principal Facts, Accuracies, Sources, Base Station Descriptions and Plots for 832 Gravity Stations of the Little Walker Volcanic Center." *California Geology*, Vol. 28 (1976), No. 5, p. 106.

Roberts, C. W., R. C. Jachens, and H. W. Oliver. "Preliminary Isostatic Residual Gravity Map of California." U.S. Geological Survey Open-File Report 81-573. (1981)

Sass, J. H., A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr. "Heat Flow in the Western United States." *Journal of Geophysical Research*, Vol. 76 (1971), No. 26, pp. 6376-6413.

Schweichert, R. A. "Shallow-Level Intrusions in the Eastern Sierra Nevada, California." Ph.D. Thesis, Stanford University. (1972)

Sharp, R. P. "Pleistocene Glaciation, Bridgeport Basin, California." *Geological Society of America Bulletin*, Vol. 83 (1972), pp. 2233-2260.

Sheridan, M. F. "Guidebook to the Quaternary Geology of the East-Central Sierra Nevada." Phoenix, Ariz., Le Beau Printing Company, 1971.

Slemmons, D. B. "Geology of the Sonora Pass Region." Unpublished Ph.D. Thesis, University of California, Berkeley. (1953)

Stanford Geological Survey. "Geologic Map of the Antelope Valley Area, Mono County, California." Stanford University, unpublished mapping, scale 1:62,500. (1964)

Thompson, G. A. and M. Talwani. "Crustal Structure From Pacific Basin to Central Nevada." *Journal of Geophysical Research*, Vol. 69 (1964), No. 22, pp. 4813-4837.

Truesdell, A. H. and R. O. Fournier. "Calculatio of Deep Temperatures in Geothermal Systems from the Chemistry of Boiling Spring Waters of Mixed Origin," in [illegible], 1975, Vol. 1 (1976), pp. 837-844.

Truesdell, A. H. and R. O. Fournier. "Procedure for Estimating the Temperature of Hot-Water Component in a Mixed Water Using a Plot of Dissolved Silica Versus Enthalpy." *Journal Research, U.S. Geological Survey*, Vol. 5, No. 1 (January-February 1977), pp. 49-52.

U.S. Geological Survey (1956) - 15-Minute Topographical Quadrangle Map Series:
Desert Creek Peak, Nevada - California
Fales Hot Springs, California - Nevada
Matterhorn Peak, California
Sonora Pass, California
Topaz Lake, California - Nevada
Tower Peak, California

U.S. Geological Survey. "Aeromagnetic Map of Parts of the Walker Lake, Reno, Chico and Sacramento 1¼ x 2¼ Quadrangles, Nevada - California." U.S. Geological Survey Geophysical Investigations Map GP-751. (1971)

Waring, G. A. "Springs of California." U.S. Geological Survey Water-Supply Paper 338. (1951)

Waring, G. A. "Thermal Springs of the United States and Other Countries of the World - A Summary." U.S. Geological Survey Professional Paper 492. (1965)

White, D. E. "Assessment of Geothermal Resources of the United States-1975." U.S. Geological Survey Circular 726. (1975)

Zietz, Isidore, P. C. Bateman, J. E. Case, M. D. Crittenden, Jr., A. Griscom, E. R. King, R. J. Roberts, and G. R. Lorentzen. "Aeromagnetic Investigation of Crustal Structure for Strip Across the Western United States." *Geological Society of America Bulletin*, Vol. 80 (1969), pp. 1703-1714.

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